Evaluation of stormwater harvesting sites using multi criteria decision methodology

Inamdar, Prasad Mohanrao, Sharma, Ashok, Cook, S and Perera, B. J. C (2018) Evaluation of stormwater harvesting sites using multi criteria decision methodology. Journal of Hydrology, 562. 181 - 192. ISSN 0022-1694

Manuscript prepared for

Journal of Hydrology

April 2018

Evaluation of Stormwater Harvesting Sites Using Multi Criteria Decision Methodology

P.M. Inamdar [a,c], A. K. Sharma [a,b], Stephen Cook[d] and B.J.C. Perera[a,b]

[a]College of Engineering and Science, Victoria University, P.O. Box 14428, Melbourne, VIC 8001, Australia

[b] Institute of Sustainability and Innovation, Victoria University, P.O. Box 14428, Melbourne, VIC 8001, Australia

[c]Department of Primary Industries, Locked Bag 5123, Parramatta, NSW 2124, Australia

[d]CSIRO, Land and Water, Highett, Melbourne, VIC, Australia

Corresponding author:
Dr. P. M. Inamdar
Department of Primary Industries
Level 10, Valentine Avenue
Locked Bag 5123,
Parramatta, NSW 2124,
Australia
P: +61 2 8838 7870
Email: prasad.inamdar@dpi.nsw.gov.au

Abstract

Selection of suitable urban stormwater harvesting sites and associated project planning are often complex due to spatial, temporal, economic, environmental and social factors, and related various other variables. This paper is aimed at developing a comprehensive methodology framework for evaluating of stormwater harvesting sites in urban areas using Multi Criteria Decision Analysis (MCDA). At the first phase, framework selects potential stormwater harvesting (SWH) sites using spatial characteristics in a GIS environment. In second phase, MCDA methodology is used for evaluating and ranking of SWH sites in multi-objective and multi-stakeholder environment.

The paper briefly describes first phase of framework and focuses chiefly on the second phase of framework. The application of the methodology is also demonstrated over a case study comprising of the local government area, City of Melbourne (CoM), Australia for the benefit of wider water professionals engaged in this area. Nine performance measures (PMs) were identified to characterise the objectives and system performance related to the eight alternative SWH sites for the demonstration of the application of developed methodology. To reflect the stakeholder interests in the current study, four stakeholder participant groups were identified, namely, water authorities (WA), academics (AC), consultants (CS), and councils (CL). The decision analysis methodology broadly consisted of deriving PROMETHEE II rankings of eight alternative SWH sites in the CoM case study, under two distinct group decision making scenarios.

The major innovation of this work is the development and application of comprehensive methodology framework that assists in the selection of potential sites for SWH, and facilitates the ranking in multi-objective and multi-stakeholder environment. It is expected

that the proposed methodology will assist the water professionals and managers with better knowledge that will reduce the subjectivity in the selection and evaluation of SWH sites

Keywords: Stormwater Harvesting, MCDA, Decision Making, Stakeholder Engagement

1. Introduction

Among several alternative water resources available for reuse, stormwater is the most preferred by the general public, especially when compared to recycled wastewater (Mitchell et al. 2002). Stormwater harvesting (SWH) and reuse is a widely used practice which deals with collection, storage, treatment and distribution of stormwater systems (Goonrey et al. 2009; Hatt et al. 2006; Sharma et al. 2012a; Sharma et al. 2013). Key benefits of stormwater harvesting have been demonstrated in terms of efficient use of existing natural resources, reduction in pollutant loads in the waterways, reduced pressure on existing water infrastructure, and flood control and protection (Mitchell et al. 2007).

The selection and evaluation of SWH sites is a spatial problem. The performance of stormwater systems in meeting the desired objectives will strongly depend upon the spatial characteristics of the catchment such as availability of stormwater supply, intended end use demands, water quality and distance from stormwater sources to end use locations. In addition, SWH and reuse schemes need significant physical area and financial investment (Sharma et al. 2016) for installing associated infrastructure (i.e. collection, storage, treatment and maintenance systems).

In this regard, the selection of suitable SWH sites is of key priority for urban water infrastructure planners. In Australian cities, generally the large scale SWH schemes are implemented on existing parks, council reserves, or other open spaces. Currently, there is no clear guidance available to select the best SWH site out of many potential sites in the area. Existing selection approaches are ad-hoc and use subjective knowledge of urban water managers to short-list the potential SWH schemes.

Apart from site selection, SWH infrastructure planning is complex and dynamic, where systems are expected to achieve several objectives such as maximizing the reliability of supply, minimizing the public health risks, minimizing the impact on environment and minimizing the supply cost. In this context, the focus of urban water managers has shifted to address these real-world problems through Multi Criteria Decision Analysis (MCDA) which is capable in providing multi-objective assessment of SWH systems and options (Brans 2002; Kodikara 2008).

MCDA is a widely used decision making tool in water resource management decision making including in SWH systems (DEC 2006; Taylor 2005, Zardari 2015). MCDA can provide decision aid for SWH systems decision making for their option assessment for selection under conflicting objectives along with different interests of stakeholders. For example, a SWH project may have an objective of minimizing the project cost, while at the same time trying to improve the aesthetic and social values for community welfare which may increase the cost of the scheme. The MCDA methods can also assist decision makers to account for the inherent conflicts and trade-offs among such objectives and to rationalize the comparison among different decision options (Kodikara et al. 2010).

Currently, there are various assessment frameworks developed for the evaluation of urban water servicing systems in the literature (Goonrey et al. 2009; Mitchell et al. 2006; Sharma et al. 2009; Sharma et al. 2010; Zhang et al. 2009). These frameworks commonly evaluate urban water systems alternatives by integrating various analysis methods and tools such as hydrological modelling, water balance analysis, life cycle costing, social analysis as well as stakeholder involvement. However, these frameworks are not exclusively applicable for selection and evaluation of SWH systems. Considering this knowledge gap, a framework is presented in this paper for evaluation of urban SWH sites.

This paper initially outlines the theoretical foundations of MCDA methods, including the selected PROMETHEE methodology (Pomerol and Barba-Romero, 2000), and associated preference elicitation of different stakeholders. Then, it discusses in detail the development and evaluation of economic, environmental and social performance measures. Also, this paper presents the application of the framework to a case study of City of Melbourne (CoM) where ranking of SWH sites is obtained in a multi-objective and multi-stakeholder environment.

2. Framework for Evaluation of Stormwater Harvesting Sites

The framework presented in this paper is aimed at developing a comprehensive methodology for identifying and evaluating SWH sites in urban areas. Figure 1 shows the broad outline of the proposed framework.

The framework has two key phases, which are described below:

Phase 1 - Development of a GIS based screening methodology for identification and selection of a set of suitable SWH sites.

The details of the GIS screening methodology (Phase 1) have been described in Inamdar et al. (2013) along with its application to a City of Melbourne case study area. In summary, the GIS based screening methodology was developed using the following steps:

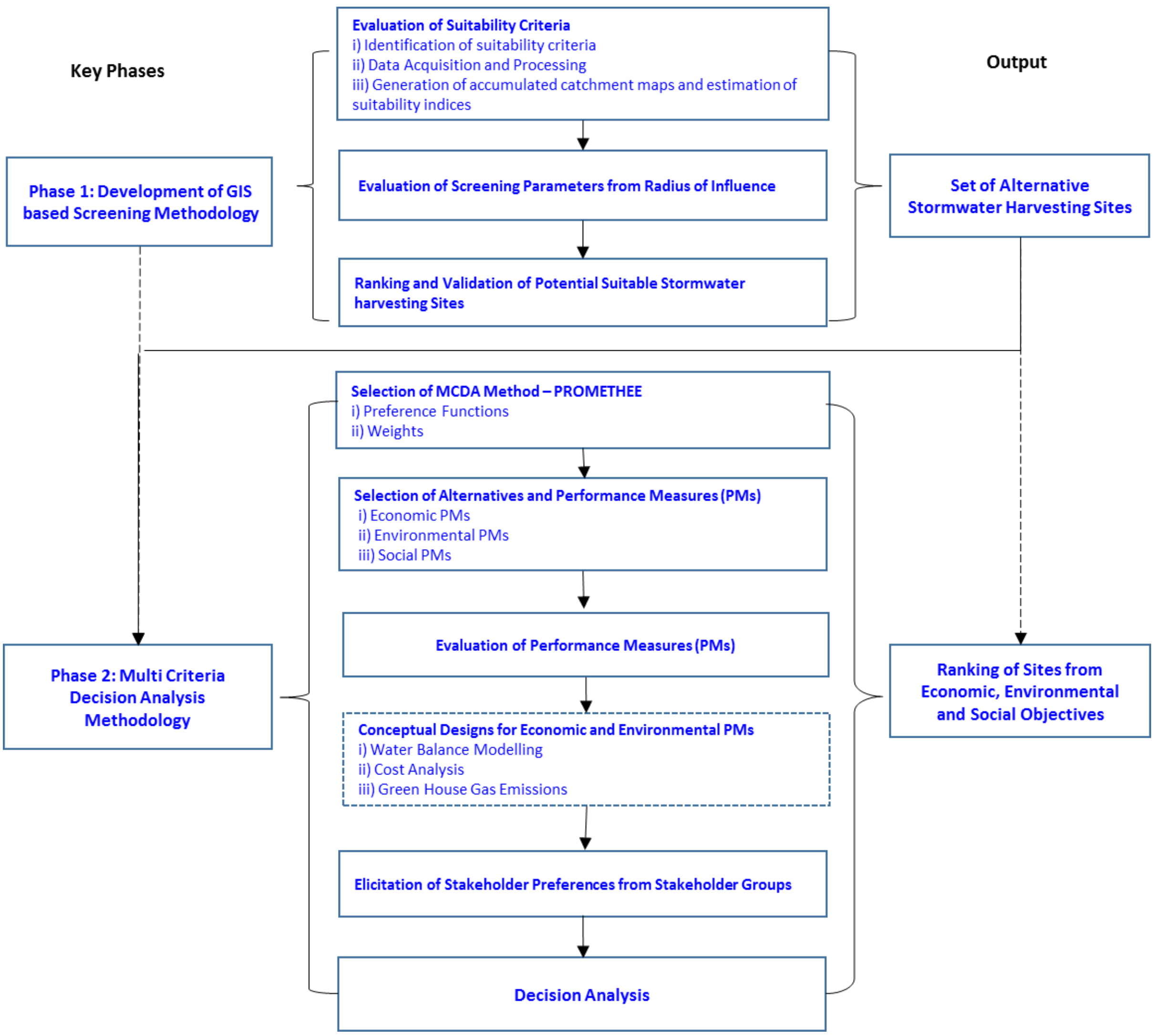

Figure 1: Outline of Proposed Framework for Selection and Evaluation of Stormwater Harvesting Sites

- Step 1 - Evaluation of suitability criteria: Annual runoff and non-potable demand were considered as the suitability criteria, as they are the principal drivers for any SWH scheme. The concept of accumulated catchment was developed for estimating runoff and demand. Spatial maps were generated for runoff, demand and accumulated catchments, which required the collection of data such as rainfall, water demands, impervious-pervious areas, digital elevation model (DEM), and digital cadastre.

- Step 2 - Estimation of environmental flows: This step involved the estimation of environmental flows. The pre-development flows were considered in this step as the environmental flows which should be released to the receiving waters before deciding the amount of stormwater for harvesting from the SWH scheme.

- Step 3 - Evaluation of screening parameters considering the radius of influence of the SWH site, which is defined as the distance from the harvesting point (outlet) to the point of demand. This included identifying: demand, ratio of runoff to demand and weighted demand distance within the radius of influence of the SWH site.

- Step 4 - Ranking and validation: This step included ranking of harvesting sites based on the evaluation of screening parameters (i.e. high demand, highest ratio of runoff to demand and lowest weighted demand distance), and their validation by the local water experts to test the developed methodology outcomes in terms of ranking of sites are consistent with the local knowledge of these experts.

A set of potential SWH sites selected from Phase 1 is considered for further assessment based on economic, environmental and social performance measures in Phase 2.

Phase 2 - Evaluation of potential harvesting sites identified in Phase 1, through MCDA considering several economic, environmental and social objectives, under different stakeholders' perspectives.

In the second phase, the MCDA evaluation is used to facilitate the rankings of SWH sites (obtained from Phase 1). It should be noted that Phase 1 ranking (GIS) is conducted using spatial information to shortlist and identify potentially suitable sites (Inamdar et al. 2013), while ranking in Phase 2 is done via a comprehensive MCDA evaluation considering several economic, environmental and social objectives. The activities/approaches involved in Phase 2 are detailed in Section 3 below.

3. Multi Criteria Decision Analysis (MCDA)

A classic MCDA model considers a finite set of decision options (or alternatives) from different perspectives which need to be ranked or scored by the decision maker (DM) under a family of performance measures (or criteria). The generic MCDA problem is structured by careful selection of performance measures (PMs) representing the objectives of the decision problem (Sharma et al. 2009; Sharma et al. 2010). Moreover, the PMs describe quantitative/qualitative attributes of alternatives, typically measured in different units. The alternatives and performance measures together form the 'evaluation matrix' (or decision matrix) which can be solved by different MCDA methods.

3.1 Selection of MCDA method - PROMETHEE

The suitable method for the MCDA analysis can be selected based on the objective problem formulation and assessment needs. Many authors have classified different MCDA methods in various forms (Rowley et al. 2012, Hajkowicz and Collins 2007; Huang et al. 2011; Pomerol and Barba-Romero 2000). The main differences in various MCDA methods are identified based on the methodology used, their user-friendliness, and the sensitivity tools they offer (Brans 2002).

For the assessment framework proposed in this paper, an outranking method PROMETHEE is recommended based on its non-compensatory properties (i.e. not allowing trade-off between sustainable objectives), ease of use, and availability of commercial software (Pomerol and Barba-Romero 2000). Additionally, there has been a growing trend to include active engagement and collaboration between stakeholders in policy making and planning processes for SWH projects (DEC 2006). The PROMETHEE method has been found effective in integrating diverse views of stakeholders through its group decision making capabilities (Kodikara et al. 2010).

3.1.1 Inputs to PROMETHEE II

The PROMETHEE II method builds on the principle of preference aggregation in pair-wise comparison of alternatives against each defined PM. All possible combinations of alternatives are evaluated according to different PMs which need to be maximized or minimized. Apart from the basic data required on the evaluation matrix, PROMETHEE II further requires two datasets of additional information (from DMs) in terms of preference functions and weights. These are described in the following sections.

3.1.1.1 Preference Functions

During evaluation of a given pair of alternatives, PROMETHEE II considers the magnitude of the differences(x) between each PM value between the two alternatives. If this deviation is large, then higher preference is given to the better alternative. Similarly, smaller deviations on alternatives are treated as weak preference or indifference. To represent this deviation, PROMETHEE II uses the concept of preference function, p(x), in pair wise comparison of alternatives. For a given PM, the preference function (PF) translates the deviation (x) between the PM values of the two alternatives, to a preference degree (or preference intensity), which has a value between 0 and 1.

For the assignment of preference functions on PMs, the authors of PROMETHEE II (Brans and Mareschal, 2005) proposed six basic shapes. These shapes are named as Usual criterion (Type I), U-shape criterion (Type II), V-shape criterion (Type III), level criterion (Type IV), V-shape with indifference criterion (Type V) and Gaussian criterion (Type VI).

Among these six shapes, the qualitative PMs used in this SWH framework can be best represented by Type I function, while the quantitative PMs can be represented by Type V function as suggested by Brans and Mareschal (2005).

There are three preference function thresholds (p, q and s), which can be used to describe any of the above six preference functions (Brans and Mareschal 2005). The indifference threshold, q represents the largest difference in PM values until which DM thinks that the preference between alternatives a and b is negligible or indifferent. The preference threshold, p, represents the smallest difference in PM values that is considered as crucial in generating strong preference of one alternative over the other. The Gaussian threshold (s) serves as intermediate preference value between p and q.

The preference thresholds aim at modelling the preferences of the DMs realistically which gradually increase from indifference to strict preference while comparing the alternatives on the given PM (Haralambopoulos and Polatidis, 2003). Estimation of these threshold values requires a significant subjective input by the DMs which in turn can bring the uncertainty in the MCDA modelling.

There is very little literature available in elicitation of preference thresholds (p, q, and s) and deriving the preference functions for outranking methods. Most of the studies employ the direct method of asking DMs to specify the appropriate PF and associated thresholds (Mutikanga et al., 2011; Silva et al., 2010). In the current study, such a direct approach is used in elicitation of the preference function parameters from the stakeholders.

3.1.1.2 Weights

Weights in PROMETHEE II represent the relative importance of the different PMs from the DM perspective. In PROMETHEE II, the set of weight $\{W_j, j = 1,2, \ldots n\}$ for n number of

PMs is obtained such that, normalised weights add up to 1 (i.e. $\sum_{j=1}^{n} W_j$=1). The PMs with higher weights are considered important by the DM and vice versa.

There are several methods available in the literature for elicitation of weights in the MCDA/PROMETHEE context. Some of these methods are direct evaluation methods, entropy methods (Zeleny, 1982), Revised Simo and Analytical Hierarchy Process (AHP) (Saaty, 2003). Details of these methods can be found in Pomerol and Barba-Romero (2000).

Among the weighting methods, the AHP enables weight elicitation in a systematic way, breaking the complex decision problem into a hierarchy of objectives and PMs. Weights on PMs are derived through this hierarchy so that the output result (i.e. scores on alternatives) is a multi-level weighted sum (Pomerol and Barba-Romero, 2000). The AHP method conducts pair-wise comparisons of PMs (similar to PROMETHEE) to elicit the weights. Precisely, the weights derived from the AHP are the eigenvectors obtained from the pair-wise comparison matrix of hierarchical elements (objectives/PMs).

Macharis et al. (2004) strongly recommended the combination of PROMETHEE with AHP for ranking of options considering hierarchical property of AHP in the context of determination of weights. Considering these benefits, AHP is proposed in this study to derive the weights in the study.

3.1.1.3 Ranking of Alternatives

Once preference function and weights are obtained for each PM, the PROMETHEE II method estimates net outranking flow by two key steps as described below (Brans and Mareschal 2005):

Step 1: Building of outranking relationship

Considering the evaluation of finite set **A** of ***m*** possible alternatives, [$a_1, a_2, \ldots a_i \ldots, a_m$] and family of ***n*** PMs, [$f_1(.), f_2(.) \ldots\ldots f_j(.) \ldots. , f_n(.)$], the preference elicitation is facilitated to derive the set of relative weights, [w_j, $j=1,2,\ldots.n$], and the set of generalized preference function types, [$F_j(x)$, $j=1,2,\ldots,n$].

For given pair of alternatives say (a and b) belonging to set **A**, the preference function denotes the preference of alternative a over b, and can be expressed $P_j(x)$ *for Performance Measure j,*

where, $P_j(a, b) = f_j(a) - f_j(b)$

The outranking relation for the pair of alternatives (a, b) can be represented by a multi-criteria preference index which indicates the degree of preference such that

$$\pi(a,b) = \sum_{j=1}^{n} W_j P_j(a,b) \qquad (1)$$

$$\pi(b,a) = \sum_{j=1}^{n} W_j P_j(b,a)$$

Where, $\pi(a, b)$ = Preference degree with which *a* is preferred over *b,*

$\pi(b, a)$ = Preference degree with which *b* is preferred over *a,* and

W_j = Relative weight of importance for PM $_j$

Step 2: Ranking of alternatives using outranking relations

Decision aid in PROMETHEE II can be achieved by estimating and comparing the outgoing flow, Φ^+ *(a)* and the incoming flow, Φ^- *(a)* at each alternative. These flows are represented as follows

$$\Phi^+(a) = \frac{1}{n-1}\sum_{i=1}^{n} \pi(\mathrm{a},\mathrm{i})$$

$$\Phi^-(a) = \frac{1}{n-1}\sum_{i=1}^{n} \pi(\mathrm{i},\mathrm{a}) \qquad (2)$$

The positive flow Φ^+*(a)* defines the strength of alternative *a* in outranking the remaining (n-1) alternatives. Higher the Φ^+*(a),* better is the alternative. Similarly, the negative flow Φ^- *(a)* defines the weakness of alternative *a*, and signifies the degree by which *a* is outranked by other (n-1) alternatives. Higher the Φ^-*(a),* worse is the alternative.

PROMETHEE II provides complete ranking through net outranking flow Φ (*a*) for alternative *a*, which can be expressed as

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \qquad (3)$$

Similarly, net outranking of all the alternatives can be estimated. The alternative with highest net outranking flow is considered as best and vice versa. Further technical details on PROMETHEE (and associated variant methods) can be found in Brans and Mareschal (2005).

3.2 Selection of Performance Measures

As stated in Section 3, the decision matrix consists of alternatives and their corresponding PMs. For the decision matrix in this study, the set of alternative SWH sites is obtained using the GIS based screening methodology as described in Phase 1 (Inamdar et al., 2013). In general, the selection of PMs for the MCDA evaluation is decided in consultation with stakeholders associated with SWH projects who have a good knowledge of the area and local needs. The PMs used in this study are based on literature review and discussions with stakeholders such as academics, water authorities, councils and consultants, and are described in Sections 3.2.1 to 3.2.4.

3.2.1 Economic PMs

Life Cycle Costing (LCC) is a widely used approach in economic assessment of SWH projects (Australian Standards 1999; DEC 2006; Mitchell et al. 2006; Taylor 2005). A simplified and equivalent approach to life cycle costing is to calculate the net present value (NPV) of project's capital and operating costs of a project (DEC 2006; Mitchell et al. 2006; Sharma et al. 2009; Swamee and Sharma 2008).

Based on NPV estimations, the current study uses Levelised Cost (LC) as a performance measure for economic assessment of SWH projects. LC has been recommended in the literature as it represents the life cycle costs of the SWH schemes (DEC 2006). LC can be defined as the net present value of the project's infrastructure costs over the analysis period divided by the net present value of total volume of water supplied over the same period. It is expressed in units of cost per KL.

3.2.2 Environmental PMs

One of the important environmental considerations for SWH projects is to improve water quality of stormwater before reuse. To support this consideration, SWH projects are often assessed by comparing the pollutant loads removal with standard best practice targets set by the designated local/state regulators for end use based on the fit for purpose concept. The common pollutants considered for removal are Total Suspended Solids (TSS), Total

Phosphorous (TP) and Total Nitrogen (TN). The loads of these pollutants are often expressed in the form of Annualised Removal Costs (ARC) which are then served as important PMs to meet environmental objectives for the proposed framework. The ARC ($/kg/Year) for pollutants represents the cost required to remove each kg of pollutants (TSS, TN and TP) per year over the life of SWH schemes.

According to Sharma et al. (2009), environmental impacts also arise from Green House Gas (GHG) emissions generated from the energy required for the operation of the services and embodied energy in manufacturing the infrastructure required for various service provisions. They reported that GHG emissions are mainly linked with operational electrical energy for servicing, which are responsible for 85-90% of the total emissions. Therefore, the present framework considers GHG emission from operational energy only as a performance measure for comparing the environmental impacts associated with SWH sites, neglecting the embodied infrastructure energy.

The proposed framework in this paper also considers Potable Water Savings (PWS) generated from SWH schemes as an important performance measure under the environmental objective. It has been considered that the potable water savings are equally proportional to stormwater usage. The SWH sites with a higher potential to replace potable water, represent improved sustainability.

3.2.3 Social PMs

The determination of social PMs can be subjective depending on the scope of the study. In the literature, public perceptions and acceptance of water reuse are recognised as the main drivers of success for any reuse project including SWH schemes (DEC 2006). Mitchell et al. (2006) demonstrated that community acceptance for SWH is a function of the degree of human contact. The authors further showed that support for the SWH decreases with more personal end use such as kitchen and shower. Community acceptance is generally very high where end-use of stormwater is limited to meet the irrigation demand of the parks (DEC, 2006).

The present study is associated with SWH for the irrigation of local council's parks and gardens, and thus community acceptance has been considered as critical social PM which is measured here in terms of degree of stormwater available in meeting irrigation demands from a given site. The community acceptance will be high for the site where stormwater can meet a larger component of high irrigation demand of that site. This performance measure can be evaluated qualitatively in terms of a 1 to 5-point scale (with 5 being very high acceptance and 1 being lowest).

Apart from the public acceptance, the recreational value of SWH sites can be considered as an important social PM for this framework. This is also described in the literature as 'aesthetic benefits/value' (Philp et al., 2008; Taylor, 2005). The recreational value of SWH sites depend on the number of sports fields, water bodies, and the popularity of these sites for recreational activities. In the present framework, the alternative sites with large number of sport fields and recreational activities can be rated high (5) for recreational value and vice versa.

Risks associated with SWH are considered as a critical PM in various studies (Taylor 2005; DEC 2006). In general, SWH studies assess environmental, public health and safety associated risks (Taylor 2005; DEC 2006). As per NRMMC (2009) guidelines on stormwater harvesting and reuse projects, small-to-medium stormwater reuse schemes involving open space irrigation (as in current study) can be readily managed using standard practices to minimise health and environmental risks. Additionally, the health and environmental risks (pollutants, GHG emissions etc.) are explicitly handled in the environmental objective and therefore they are not considered separately in the social objective.

The proposed framework considers risks associated with the construction of the project as one of key PMs. The user can conduct basic or detailed construction risk assessments for SWH sites, which can be determined by multiple factors, and are generally location specific. Construction risks can be estimated by considering number of factors such as location of nearby existing drainage asset (to minimize construction), availability of sufficient storage, presence of heritage or culturally significant places near sites, or presence of possible service disruptions such as electricity poles/transformers, tram crossings lines near sites. Each site can be ranked separately on multiple factors using a predefined qualitative scale of 1-5. The ranking obtained from these multiple factors can be summed to derive the total combined ranking score. It should be noted that this total combined score needs to be standardised into 1-5-point scale which can be used in estimating the overall construction risks for all sites.

3.2.4 Summary of PMs Considered

Table 1 provides the summary of all PMs considered in the proposed framework under economic, environmental and social objectives. It should be noted that each PM in Table 1 needs to be either minimized or maximized with respect to relevant objectives in the MCDA evaluation of alternative SWH sites obtained from the GIS screening methodology.

The user can select study specific appropriate sub-PMs under these three categories for MCDA application.

Table 1: Summary of PMs Selected for the Study

Objectives	Performance measures	Unit	Max or Min
Economic	Levelised Cost	($/ kL)	Min
Environmental	Green House Gas Emissions	(Kg CO_2 /kL)	Min
	Potable Water Savings	ML	Max
	Annualised Removal Cost of TSS	($/ Kg/Year)	Min
	Annualised Removal Cost of TP	($/ Kg/Year)	Min
	Annualised Removal Cost of TN	($/ Kg/Year)	Min
Social	Community Acceptance	-	Max
	Construction Risks	-	Min
	Recreational Values	-	Max

3.3 Estimation of Performance Measures

The estimation of PMs for use in MCDA is required to characterise and quantify the alternative SWH sites. The PMs described under economic and environmental objectives are quantitative, while PMs under social objectives are qualitative (Table 1). Estimation of qualitative PMs in this framework is done using qualitative scales as discussed in Section 3.2.3.

3.3.1 Quantitative PMs –Environmental and Economic PMs

To estimate the quantitative PM values for selected SWH sites, water balance modelling and conceptual designs are conducted for key SWH system components, namely collection, storage, treatment and distribution. Table 2 briefly describes the approaches used for estimating environmental and economic PMs. Details of the estimation of these PMs are given in Sections 3.3.1.1 to 3.3.1.3

Table 2: Approaches used for evaluation of Economic and Environmental PMs

PM Type	Derived PM	Approach
Economic	Levelised Cost	Conceptual designs are developed for stormwater infrastructure (i.e. stormwater storage and treatment sizing along with water balance modelling and then design of collection and distribution system). The detailed approach is specified in Section 3.3.1.1. Levelised costs of designed stormwater infrastructure are then estimated through the standard approach specified in Section 3.3.1.2
Environmental	Potable Water Savings	Estimate stormwater quantity available for end use (for irrigation here) based on Water Balance Modelling and optimal sizing of stormwater storage and associated volumetric reliability as part of conceptual design as specified in Section 3.3.1.1
	Annualised Removal Cost of TSS, TP, TN	Conduct conceptual design of stormwater treatment unit sizing and associated cost for pollutant load removal as per prescribed local guidelines. Also estimate pollutant loads removed as specified in Section 3.3.1.1 Annualised Removal Cost of TSS, TP, TN for each SWH site are then estimated through the standard approach specified in Section 3.3.1.2
	Green House Gas (GHG) Emission	Conceptual design of stormwater infrastructure for GHG emission analysis from energy use as described in Section 3.3.1.3

3.3.1.1. Water Balance Modelling and Conceptual Designs for Stormwater Infrastructure

The water balance modelling and conceptual designs are an integral part of SWH projects. Considering the seasonal variability of runoff and demand, water balance modelling determines the ability of the SWH site in meeting the desired end uses and environmental water quality through a simulation of conceptual designs. For this purpose, software tools such as MUSIC (http://ewater.org.au/products/music/) can be used to ensure that the sizing of stormwater storage and treatment units are adequate in meeting the specified stormwater quality and quantity objectives.

From water balance modelling, the PWS (environmental PM) from SWH schemes can be estimated for selected stormwater sizes to achieve the desired volumetric reliability. Additionally, the water balance modelling can provide information on required pollutant removal loads of TP, TN and TSS (in kg) from the SWH schemes which further can be used in determining the annualised removal cost of pollutants (environmental PM).

In terms of SWH sites, the conceptual designs can assist in determining the various infrastructure provisions (such as storage size/treatment options, conveyance pipes, pumping mains and pump sizes) and associated costs. Additionally, the environmental PMs such as greenhouse gas emission and pollutant loads removal can also be derived from the conceptual designs of various SWH system components.

3.3.1.2 Cost Analysis of Designed Infrastructure

As described in Sections 3.2.1 and 3.2.2, the cost analysis for SWH sites can be conducted for estimating the *Levelised Cost* (economic PM) and *Annualised Removal Cost (ARC) of*

Pollutants (environmental PM) for use in the MCDA. More importantly, conceptual designs developed for stormwater infrastructure form the basis for cost analysis of SWH sites.

Levelised Cost *(*LC) for the present study can be defined as

$$LC = \frac{NPV\ of\ total\ stormwater\ infrastructure\ of\ site\ (\$)}{NPV\ of\ volume\ of\ stormwater\ supplied\ by\ the\ site\ (kL)} \qquad (4)$$

In the above equation, the Net Present Value (NPV) of total infrastructure cost can be obtained by summing NPV of capital and operational costs of all components associated with each selected site for MCDA over the analysis or design period. The NPV estimation can be based on the method described by Newnan et al. (2002). Similarly, the NPV of volume of stormwater supplied can be considered equivalent to potable water savings (volume of potable water supplied/ required if stormwater system is not available) at each site over the life of the system or design period. The volume of stormwater supplied (available for use) can be determined using water balance modelling.

For each selected SWH site, the annualised removal costs (ARC) of pollutants (TSS, TP and TN) can be determined using the approach adopted in MUSIC software (eWater, 2012). Initially the annualised cost of treatment needs to be estimated by dividing the NPV of treatment costs by the analysis period. The treatment costs can vary depending on selection of infrastructure. Furthermore, for estimating the ARC of pollutants, the annualised NPV can be then again divided by the pollutant loads estimated for each selected SWH site from water balance modelling.

Mathematically, ARC for SWH site can be estimated as:

$$\text{Annualised Removal Cost of Pollutant} = \frac{\text{Annualised NPV of Treatment} \quad \text{Cost}}{\text{Pollutant Load (Kg/Year)}} \tag{5}$$

$$Annualised\ NPV\ of\ Site = \frac{\text{Total NPV of Treatment Cost}}{\text{Analysis Period}} \tag{6}$$

3.3.1.3 Greenhouse Gas Emissions Estimation Analysis

The greenhouse gas (GHG) emissions in SWH schemes are mostly associated with electrical energy consumption from pumps. Therefore, the GHG emissions for a selected SWH site can be considered as the product of electrical energy consumption of the pumps (designed as part of conceptual designs) and GHG Emissions factor associated with electricity consumption.

3.4 Elicitation of Preferences from Stakeholder Groups

Many studies in the literature have highlighted the well-established fact that stakeholder participation can effectively contribute to successful sustainable stormwater management (Barbosa et al., 2012; Mankad and Tapsuwan, 2011; Sharma et al., 2012a, Sharma et al., 2016). For the SWH projects, key stakheholder groups generally are local councils, associated water authorities, research bodies, private consultants and state regulatory departments. Each of these stakeholder groups may have different perspectives on SWH objectives, and hence it is essential to account for the varied stakeholder preferences on SWH systems.

Taylor (2005) provided a detailed review of stakeholder preference elicitation methods in the context of MCDA assessment of stormwater projects. Some of these methods include direct methods such as consensus conference, citizen’s jury and expert panel, and indirect methods such as Delphi and workshops. Selection of the suitable elicitation method for any project depends on multiple factors, such as time available (to use such methods), human resources, and associated costs. Among different methods, the workshop method, which is mixed method incorporating approaches from direct and indirect methods, which can serve as a simple and a quick consultation process, offering group discussions and group learning. In terms of stormwater harvesting, the workshop method can assist in prioritizing the conflicting objectives or policies from different stakeholders such as Government, community and water authority. Considering these advantages, the workshop method is recommended as the stakeholder preference elicitation method for the current study.

In MCDA methods, the stakeholder preferences are used as input to compare and establish the ranking between the given set of alternatives (Öztürké et al. 2005). In the current framework, the preferences elicitation for the recommended MCDA method PROMETHEE requires DM input on PM (Table 1) in terms of two preference parameters, namely, preference functions (Section 3.1.1.1) and weights (Section 3.1.1.2). With the selected workshop method, these preferences can be obtained from different stakeholder groups with limited resources in terms of cost and time.

3.5 Decision Analysis of Stormwater Harvesting Sites

The alternative SWH sites with estimated economic, environmental and social PMs (Table 1) can be combined with preference parameters from stakeholder groups (Section 3.4) to conduct the decision analysis i.e. to derive the ranking of SWH sites, using the PROMETHEE II methodology (Section 3.1.1). The alternative site with highest net outranking flow is considered as the best and vice versa (Section 3.1.1.3).

In terms of ranking of SWH sites, the decision analysis can be conducted through either homogenous or collective perspectives of different stakeholder groups. This study proposes to evaluate the decision analysis under two group decision making scenarios i.e. Homogeneous Group Decision Making (HGDM) scenario and Collective Group Decision Making (CGDM) scenario.

Ranking of SWH sites in HGDM scenario can be obtained from a single or similar stakeholder group e.g. all the representatives from water utility(ies) can be part of HGDM group, reflecting decision making only from perspectives of water authority. On the contrary, ranking in CGDM scenario can be obtained by combining representatives of all the stakeholders or some of these stakeholders (i.e. water authority, local council, research bodies and private consultants). Finally, the recommendations for suitable SWH sites are made based on the ranking results coming from HGDM and CGDM scenarios.

A PROMETHEE based commercial software such as D-Sight (Hayez et al., 2012) can be used as the decision-making tool in the decision analysis process.

4. Application of MCDA to the Case Study

4.1 Case Study

The MCDA application was demonstrated in a case study of the City of Melbourne (CoM) in Australia in collaboration with the one of local water authority, City West Water (CWW) in Melbourne. The study area of CoM within the CWW servicing region is shown in Figure 2.

The study area of CoM (36.5 Km^2) comprises predominantly commercial land use; other land uses include public parks, reserves, residential and industrial. The total non-residential water demand in the study area during the year 2010 was estimated as 11 GL (gigalitres), whereas the total demand including the residential demand constituted 15 GL. This non-residential demand is mainly commercial water use which constitutes 82% (of the total non-residential demand of 11 GL).

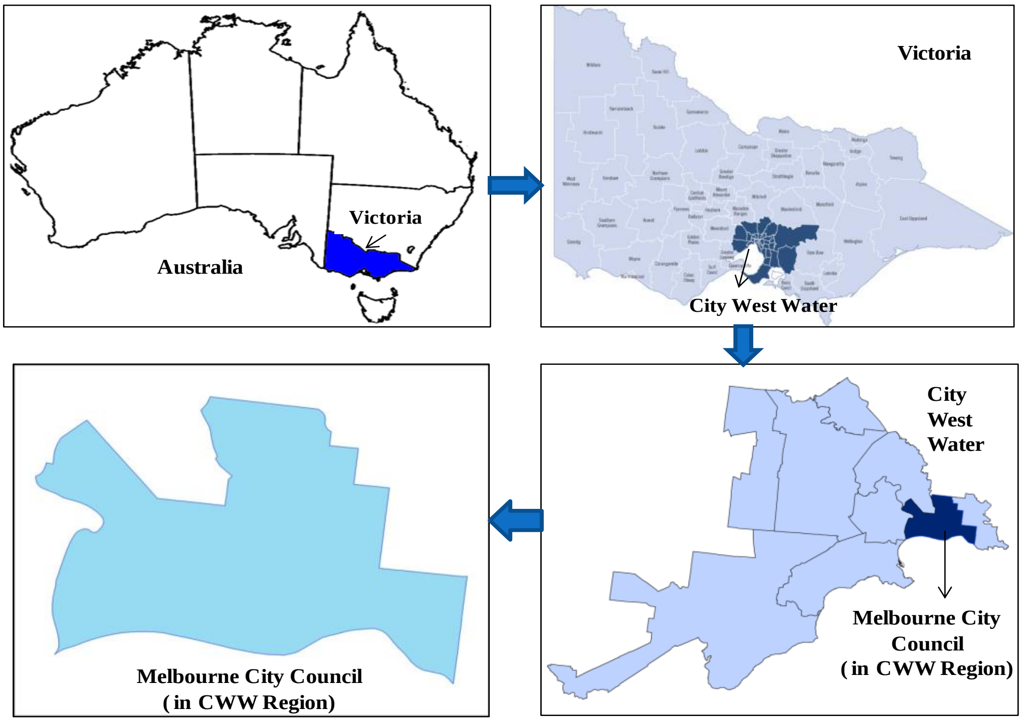

Figure 2: Case Study Area- City of Melbourne

The next highest non-residential demand results from the irrigation of parks and open spaces accounting for 6%. This high irrigation demand is currently being supplied with potable water, which is subjected to water supply restrictions. SWH and reuse options are considered to save potable water used for parks and open space irrigation.

4.2 Selection of Alternatives Stormwater Harvesting Sites

As the first phase of the framework, a GIS based screening methodology was proposed to identify and select potentially suitable harvesting sites). The application of this methodology was demonstrated over an urban area in the City of Melbourne, Australia (Inamdar et al.

2013). This application shortlisted eight SWH sites (out of 50), which were considered for MCDA application and evaluation in this paper.

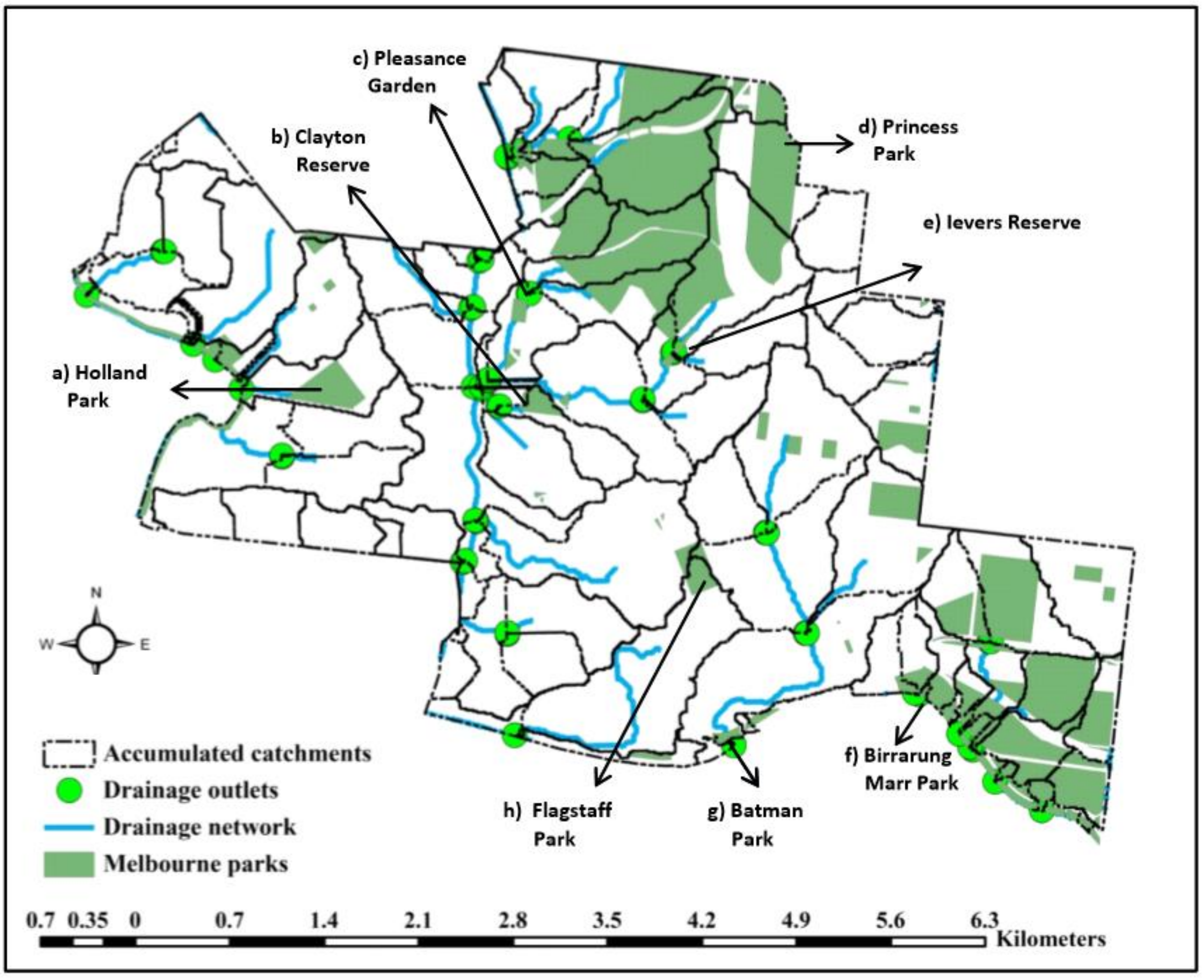

Figure 3: Spatial Locations of Alternative Stormwater Harvesting Sites

Figure 3 shows the spatial locations of alternative SWH sites obtained from the application of the GIS screening tool for the case study area. These sites were validated for SWH suitability through the discussions with City West Water officers (local water supply utility) who had a good knowledge of SWH practices in this area. Table 3 shows irrigation demands from these sites, with Princess Park and Flagstaff Gardens being key locations with higher demands. These SWH sites were considered as alternatives in the decision matrix of MCDA,

Table 3: Alternative Sites Selected for MCDA Evaluation

No.	Alternative Sites	Irrigation Demand, ML/Year
a)	Holland Park	23
b)	Clayton Reserve	32
c)	Pleasance Garden	7
d)	Princess Park	92
e)	Ievers Reserve	7
f)	Birrarung Marr Park	18
g)	Batman Park	7
h)	Flagstaff Park	70

4.3 Estimation of Performance Measures

A comprehensive set of nine PMs describing economic, environmental and social objectives in the context of sustainable SWH and reuse was developed as defined in Table 1. They are used to characterise and quantify the alternative SWH sites. All economic and environmental PMs are quantitative, while all social PMs are qualitative.

4.3.1 Quantitative PMs – Economic and Environmental PMs

The general approach used for estimating quantitative performance measures (i.e. economic and environmental PMs) for the case study is described in Table 2, and it was applied uniformly to all selected eight SWH sites.

4.3.1.1 Water Balance Modelling and Conceptual Designs for Stormwater Infrastructure

Water balance modelling was conducted using the MUSIC software (http://www.ewater.com.au/products/ewater-toolkit/urban-tools/music/). The modelling was conducted using a 6-minute time step for the period of 1997-2006, which represented the drought period in Victoria, representing a conservative estimate of water availability. However, the modelling can be conducted for any selected period. MUSIC modelling required input data in terms of climate data (rainfall and evapotranspiration), catchment properties (catchment type, pervious/impervious area, rainfall-runoff parameters and pollutant load parameters) and end use demands for each of selected site.

Conceptual configuration selected for modelling consisted of nodes and links representing catchment, treatment measures, storages and reticulation system. This configuration was altered for each selected site separately, depending on local physical conditions and demand. The configurations were adjusted to achieve the best practice targets (removal of 80% of TSS, 45% TP, and 45% of TN) set by the Victorian Standing Committee (1999). Such a configuration was finally adopted.

The stormwater yield estimated from the MUSIC software was considered as *potable water savings* (environmental PM) from SWH schemes. Moreover, MUSIC modelling also provided information on pollutant removal loads of TP, TN and TSS (in kg) from the catchments of all SWH sites. These loads were used in determining the annualised removal cost of pollutants, which is one of important PMs under the environmental objective. The stormwater storage sizes for adopted reliability and stormwater treatment devised for prescribed pollutant removal were estimated through water balance modelling.

4.3.1.2 Cost Analysis

The cost analysis for SWH sites was conducted for estimating the *Levelised Cost* (economic PM) using LCC approaches and *Annualised Removal Cost (ARC) of Pollutants* (environmental PM) for the MCDA.

As specified in Section 3.3.1.2, *Levelised Cost (LC)* for given SWH site was estimated as the ratio of Net Present Values (NPVs) of the total infrastructure of a SWH site to NPV of the volume of stormwater supplied (kL) by the site.

The NPV analysis for all SWH sites was done for a period of 50 years with the discount rate of 5.1% based on discussions with CWW. Similarly, the information on the useful life of various components, their capital and maintenance costs were obtained from the literature and personal communications with CWW and manufacturers. Additionally, CWW provided the design and administration costs (15% of capital costs) and the construction and project management costs (30% of capital costs) for estimating overall project cost.

Furthermore, the *Annualised Removal Cost (ARC)* estimation of pollutants (TSS, TP and TN) with respect to each site was based on determining the ratio of the annualised NPV of treatment system cost ($) and pollutant loads (Kg/year) generated from SWH sites.

4.3.1.3 Greenhouse Gas Emissions (GHG) Analysis

As specified in Section 3.3.1.3, the *GHG emissions* from a given SWH site was considered as the product of Victorian GHG Estimation Factor as 1.21 kg /CO_2/kWh (Department of Climate Change 2013) and energy consumption from electric pumps (kWh/kL) in delivering the stormwater for irrigation at a given SWH site. Here, electrical consumption (kWh/kL) was estimated by taking ratio of annual pumping energy requirement (kWh/year) to annual volume of stormwater reuse (kL/year) for each site.

4.3.2 Qualitative PMs - Estimation of Social Performance Measures

This study estimated all social PMs based on pre-defined qualitative common scale of 1-5. This evaluation of social performance measures was conducted in discussion with CWW, considering their local experience with the community and the knowledge of the case study area. Brief details on the evaluation for each social PM are given below.

Community Acceptance: This qualitative assessment was done based on perceived sustainability of SWH sites in meeting larger demands (with 5 being very high demand site and 1 being lowest demand site) and ensuring the higher water security for the community to accept the SWH scheme.

ii) Construction Risks: The construction risks (1 as lowest risk and 5 as highest risk) for selected SWH sites in this study were rated on four factors: i) location of the existing drainage asset, ii) available space for a suitable storage, iii) presence of heritage sites, and iv) presence of possible service disruptions such as electricity poles/transformers, tram crossings lines.

iii) Recreational Value: The recreational value of SWH sites was estimated with respect to the number of sports fields surrounding the sites and the popularity of these sites for recreational activities such as walking trails, bicycle paths, barbeque facilities. The alternative sites with large number of sport fields and recreational activities were rated high (5) and vice versa.

4.4 Evaluation Matrix

Table 4 shows the evaluation matrix used in this study for the application of MCDA. This table consists of alternatives SWH sites (Table 3) and economic, social and environmental PMs estimated in Section 4.3.

Table 4: Evaluation Matrix for MCDA Evaluation

Sites	Objectives								
	Economic	Environmental					Social		
	Performance Measures								
	Levelised Cost ($/kL)	Greenhouse Gas Emissions (Kg CO_2 / kL)	Potable Water Savings (ML)	Annualised removal cost ($/Kg/Year)			Community Acceptance	Recreational Value	Construction Risks
				TSS[a]	TP[b]	TN[c]			
Holland Park	15.3	0.20	18	4	2527	327	2	5	1
Birrarung Marr Park	15.5	0.17	15	0.9	580	81	2	3	2
Clayton Reserve	14.0	0.17	26	1.4	1021	122	3	3	2
Princess Park	12.3	0.16	73	2.8	1832	241	5	5	3
Flagstaff Park	10.8	0.41	56	1.4	929	118	4	4	3
Batman Park	22.3	0.18	5.7	1.6	1130	140	1	3	3
Ievers Reserve	21.4	0.18	5.7	1.1	772	95	1	3	1
Pleasance Gardens	27.2	0.17	5.6	3.3	2167	266	1	2	3

[a]TSS: Total Suspended Solids [b]TP: Total Phosphorous, [c]TN: Total Nitrogen

Although the evaluation matrix in Table 4 provides the brief information on performance of alternative SWH sites in meeting economic, environmental and social objectives, it is difficult for decision maker to select the best SWH site by analysing this diverse information presented in different units. For example, Holland Park and Birrarung Marr Park have similar economic PM value but different environmental and social PM values. Above examples highlight the importance of MCDA analysis for bringing rationality in decision making.

4.5 Elicitation of Stakeholder Preference Parameters from Stakeholder Groups

The preference elicitation procedure in the current study comprised of deriving the preference functions and weights on the performance measures (PMs) as required by the PROMETHEE II method. To obtain these preference parameters, representatives of four broad stakeholder groups were consulted as decision makers, namely water authorities (WA), academics (AC), consultants (CS) and councils (CL). A workshop was organised where eleven participants belonging to the four identified stakeholder groups expressed their preferences on the nine PMs. Among these workshop participants, four consultants, three water authority personnel, three academics and one council stormwater manager represented the CS, WA, AC and CL stakeholder groups respectively.

4.5.1 Elicitation of Preference Functions

To obtain the preference function (PF) information on PMs, the participants in the workshop were directly asked to specify the preference thresholds on respective PMs specified in the evaluation matrix (Table 4). For the quantitative PMs, the participants were requested to specify the p and q values of Type V function while for qualitative PMs, the participants were advised to use Type I function (Brans and Mareschal, 2005) as discussed in Section 3.1.1.1. This approach of specifying direct p and q values avoided the complexity of selecting PF from six available different PF types. Table 5 preference functions (p and q values) derived from all participants along with combined average values which are used in group decision making.

Table 5: Preference Function Parameters Derived from All Stakeholder Groups

Participant	PF	PM (Performance Measure)								
		Economic	Environmental					Social		
		LC	GHG	PWS	ARC			CA	CS	RV
					TSS	TP	TN			
WA-1	PF Type	V	V	V	V	V	V	I	I	I
	q	0	0	1	0	0	5	-	-	-
	p	0.5	0.1	5	0.1	0	0	-	-	-
WA-2	PF Type	V	V	V	V	V	V	I	I	I
	q	0	0	1	0	0	5	-	-	-
	p	0.5	0.1	5	0.1	0	0	-	-	-
WA-3	PF Type	V	V	V	V	V	V	I	I	I
	q	1	0.2	5	0.2	100	30	-	-	-
	p	3	1	20	1	500	100	-	-	-
AC-1	PF Type	V	V	V	V	V	V	I	I	I
	q	0.2	0.1	5	0.1	25	10	-	-	-
	p	2	0.5	10	0.5	100	50	-	-	-
AC-2	PF Type	V	V	V	V	V	V	I	I	I
	q	0.1	0.5	1	0	0	0.1	-	-	-
	p	0.5	0.8	10	0.1	0	5	-	-	-
AC-3	PF Type	V	V	V	V	V	V	I	I	I
	q	0.5	0.5	0.25	0.5	200	20	-	-	-
	p	5	2	15	1	600	60	-	-	-
CS-1	PF Type	V	V	V	V	V	V	I	I	I
	q	3	0.5	5	0.5	200	30	-	-	-
	p	6	1	10	1	500	50	-	-	-
CS-2	PF Type	V	V	V	V	V	V	I	I	I
	q	1	0.5	5	0.3	50	10	-	-	-
	p	3	1.5	10	1	150	50	-	-	-
CS-3	PF Type	V	V	V	V	V	V	I	I	I
	q	2	0.6	3	0.6	200	30	-	-	-
	p	3	1	5	1	300	50	-	-	-
CS-4	PF Type	V	V	V	V	V	V	I	I	I
	q	0.2	0.5	1	0.6	150	20	-	-	-
	p	2	1	5	0.5	400	60	-	-	-
CL-1	PF Type	V	V	V	V	V	V	I	I	I
	q	0.3	0.2	0.5	0.2	100	20	0	1	0
	p	1	0.5	5	0.5	300	50	0	2	0
Combined Avg.	PF Type	V	V	V	V	V	V	I	I	I
	q	0.7	0.05	2.5	0.2	93	16	-	-	-
	p	1.3	0.1	7	0.5	259	43	-	-	-

- LC: Levelised Cost
- GHG: Green House Gas Emission
- PWS: Potable Water Savings
- RV: Recreational Value
- CA: Community Acceptance
- CR: Construction Risks

- ARC: Annualised Removal Costs of Pollutants (TSS, TP and TN)
- TSS: Total Soluble Solids
- TP: Total Phosphorous
- TN: Total Nitrogen

4.5 2 Elicitation of Weights

As described in Section 3.1.1.2, Analytical Hierarchy Process (AHP) method was used for weights elicitation. The participants from each representative group of WA, AC, CS, and CL were requested to provide the information on the relative importance of objectives and relative importance of PMs, on a pair wise comparison scale of 1-9 as defined by AHP authors.

The pair wise comparison responses recorded from all participants were further analysed with ‘EXPERT CHOICE’, an AHP based software (http://expertchoice.com/), to compute the weights for all PMs. These weights were computed at all stages of the hierarchy of the objectives, PMs and sub-PMs from all stakeholder participant members of WA, AC, CS and CL groups.

As an example, Table 6 provides the average of final weights of all stakeholders obtained through AHP analysis. From overall weight analysis, it was seen that Levelised Cost (LC) and Potable Water Savings (PWS) were highly rated PMs among all stakeholder groups with average weight of 0.43 and 0.16.

Table 6: Final Weights on PMs by All Stakeholder Participants

Objective	PM	WA-1	WA-2	WA-3	AC-1	AC-2	AC-3	CS-1	CS-2	CS-3	CS-4	CL-1	Avg.
Economic	LC	0.6	0.34	0.25	0.2	0.25	0.4	0.5	0.54	0.54	0.57	0.54	0.43
Environment	PWS	0.06	0.13	0.2	0.4	0.23	0.21	0.14	0.11	0.1	0.07	0.09	0.16
	GHG	0.06	0.08	0.02	0.1	0.08	0.11	0.03	0.02	0.04	0.03	0.05	0.06
	TSS	0.06	0.05	0.03	0.07	0.05	0.04	0.01	0.02	0.02	0.01	0.02	0.03
	TP	0.01	0.02	0	0.01	0.02	0.02	0.04	0.01	0.01	0.01	0	0.01
	TN	0.01	0.05	0	0.02	0.01	0.02	0.04	0	0.01	0.01	0.01	0.02
Social	CA	0.06	0.11	0.2	0.05	0.16	0.1	0.08	0.08	0.09	0.08	0.09	0.10
	CR	0.06	0.11	0.1	0.1	0.05	0.05	0.08	0.17	0.07	0.08	0.16	0.09
	RV	0.09	0.11	0.2	0.05	0.16	0.05	0.08	0.08	0.12	0.13	0.05	0.10

4.6 Decision Analysis under HGDM and CGDM Scenario

Decision analysis was conducted in the form of ranking of SWH sites using PROMETHEE II. For this purpose, the estimated PM values of alternative SWH sites (Table 4) were combined with preference parameters, i.e. preference functions (Section 4.5.1) and weights (Section 4.5.2) from WA, AC, CS and CL group stakeholders. Decision analysis was conducted under two unique group decision making (GDM) scenarios, namely, Homogeneous Group Decision Making (HGDM) and Collective Group Decision Making (CGDM). The HGDM scenario facilitated decision analysis based on input from all representatives of each homogenous sub-group of stakeholders (WA, AC, CS and CL) separately, while the CGDM scenario facilitated the collective decision analysis with the all stakeholders from each sub-group of HGDM. The commercial software, D-Sight (http://www.d-sight.com/) was used as the decision-making tool in the decision analysis.

The outcome of ranking based on HGDM and CGDM scenario is shown in Table 7 for all WA, CS, AC and CL stakeholder groups. As described in Section 3.1.1.3, the PROMETHEE

II rankings were based on net outranking scores (Φ) obtained from the preferences of DMs for each of the SWH sites.

Table 7: Ranking of Alternative Sites from HGDM and CGDM Group Stakeholders

Alternative Sites	HGDM Rankings								CGDM ranking	
	WA		CS		AC		CL		Φ	Rank
	Φ	Rank	Φ	Rank	Φ	Rank	Φ	Rank		
Flagstaff Park	0.60	1	0.57	1	0.49	2	0.51	1	0.55	1
Princess Park	0.48	2	0.42	2	0.54	1	0.48	2	0.49	2
Clayton Reserve	0.26	3	0.31	3	0.40	3	0.24	3	0.31	3
Birrarung Marr Park	0.06	4	0.10	4	0.15	4	0.06	4	0.09	4
Holland Park	-0.02	5	-0.04	5	0.02	5	-0.14	5	-0.05	5
Ievers Reserve	-0.35	6	-0.30	6	-0.11	6	-0.24	6	-0.25	6
Batman Park	-0.32	7	-0.26	7	-0.33	7	-0.45	7	-0.34	7
Pleasance Garden	-0.69	8	-0.65	8	-0.43	8	-0.71	8	-0.62	8

It can be seen from Table 7 that the ranking of top three sites under HGDM by various stakeholders sub-groups and under CGDM by stakeholders as one group is very similar. The Flagstaff Park, Princess Park and Clayton Reserve consistently ranked as the top three sites under HGDM and CGDM scenarios. Also, the ranking of the intermediate (4 and 5) and low ranked sites (6 to 8) were the same for all 4 subgroups. The sites with negative Φ value in Table 7 were considered unsuitable for SWH.

The results from PROMETHEE II ranking of SWH sites obtained under the HGDM and CGDM scenario analysis indicated the Flagstaff Park was the most preferred alternative SWH site considering its top performance (Φ score). Similarly, Princess Park and Clayton Reserve emerged as the next best alternative under HGDM and CGDM scenarios. Apart from the top three alternatives, Holland Park and Birrarung Marr Park were consistently ranked in mid positions, and Pleasance Garden was rated as the lowest ranked alternative for both scenarios.

5. Conclusion

The evaluation of stormwater harvesting (SWH) sites is often complex due to significant unpredictability in physical stormwater characteristics, demand patterns and social acceptability, and several institutional and political factors. Moreover, the successful SWH projects need active collaboration and participation from different stakeholders such as the government, the water industry, and the community. These stakeholders can have their own perceptions, which may cause conflict in the desired economic, environmental, and social objectives expected from SWH projects.

This paper presents a comprehensive framework for the Multi Criteria Decision Analysis (MCDA) evaluation of SWH sites. The framework presented in this study provides information on suitable SWH site selection in urban areas and also can provide a multi-objective evaluation of SWH sites under diverse views of stakeholders. This study has successfully showed the application of a MCDA) methodology for evaluating SWH sites in the City of Melbourne (CoM) in Australia.

The MCDA evaluation in this study consisted of eight alternative SWH sites and a set of nine performance measures (PMs), representing economic, social, and environmental objectives. The study described and demonstrated various evaluation procedures to quantify the selected PMs including water balance modelling, system design, life cycle cost analysis, GHG emission analysis, and nutrient load assessment for quantitative PMs. Also, study demonstrated SWH decision making considering the perspectives of variety of stakeholders individually as well in a group environment. The results of PM evaluations for alternative SWH sites formulated the evaluation (or decision) matrix which can be assessed with any standard MCDA method including PROMETHEE as used in this study.

It is expected that the application of SWH site selection framework will help water managers in taking better informed decisions with reduced subjectivity. The water professional will be able to conduct better assessment of potential harvesting sites. The ranking of SWH sites in the current study are subject to the selected MCDA method, associated preference elicitation parameters and analysis software used. Also, this study did not focus on external uncertainties such as the effect of change in costs, interest rates, inflation, regulations, and stochastic nature of runoff and demand. These aspects of evaluation can be considered in a future study.

Acknowledgement:

The authors are grateful to College of Engineering and Science of Victoria University, Melbourne, for supporting this research as part of completed PhD project. Finally, the authors would like to thank the surface water modelling unit of Department of Primary Industries (DPI) NSW for encouragement. It is to be acknowledged that DPI NSW is not associated or endorsing any component of this research material or its results

References:

Australian Standards (1999) AS/NZS 4536:1999 Life Cycle Costing - An Application Guide. Australian Standards, Homebush, NSW, Australia

Barbosa, A. E., Fernandes, J. N., & David, L. M. (2012). Key Issues for Sustainable Urban Stormwater Management, Water Research, Volume 46, Issue 20, 2012, Pages 6787-6798, ISSN 0043-1354, http://dx.doi.org/10.1016/j.watres.2012.05.029.

Brans JP (2002) Ethics and decision European Journal of Operational Research 136:340-352

Brans JP, Mareschal B (2005) PROMETHEE Methods Multiple Criteria Decision Analysis: State of the Art Surveys:163-186

DEC (2006) Managing Urban Stormwater: Harvesting and Reuse. Department of Environment and Conservation, NSW Retrived from (http://www.environment.nsw.gov.au/resources/stormwater/ managestormwatera06137.pdf)

Department of Climate Change (2012). National Greenhouse Account Factors. Retrieved from https://www.climatechange.gov.au/sites/climatechange/files/documents /03_2013/ngafactors.pdf.

eWater. (2012). MUSIC: Online Manual Retrieved from http://training.ewater.com.au/mod/resource/view.php?id=41, Accessed on 21st March, 2013

Goonrey CM, Perera BJC, Lechte P, Maheepala S, Mitchell VG (2009) A Technical Decision-Making Framework: Stormwater as an Alternative Supply Source, Urban Water Journal 6:417 - 429

Hajkowicz S, Collins K (2007) A Review of Multiple Criteria Analysis for Water Resource Planning and Management, Water resources management 21:1553-1566

Hatt BE, Deletic A, Fletcher TD (2006) Integrated Treatment and Recycling of Stormwater, A review of Australian practice Journal of Environmental Management 79:102-113

Haralambopoulos, D., & Polatidis, H. (2003). Renewable Energy Projects: Structuring a Multi-Criteria Group Decision-Making Framework. Renewable Energy, 28(6), 961-973.

Hayez, Q., De Smet, Y., & Bonney, J. (2012). D-SIGHT: A New Decision Making Software to Address Multi-Criteria Problems, International Journal of Decision Support System Technology (IJDSST), 4(4), 1-23.

Huang IB, Keisler J, Linkov I (2011) Multi-criteria Decision Analysis in Environmental Sciences: Ten Years of Applications and Trends, Science of the Total Environment 409:3578-3594

Inamdar PM, Cook S, Sharma AK, Corby N, O'Connor J, Perera BJC (2013) A GIS based Screening Tool for Locating and Ranking of Suitable Stormwater Harvesting Sites in Urban Areas, Journal of Environmental Management 128:363-370 doi:http://dx.doi.org/10.1016/j.jenvman.2013.05.023

Kodikara P (2008) Multi-Objective Optimal Operation of Urban Water Supply Systems,- PhD Thesis. Victoria University

Kodikara P, Perera BJC, Kularathna M (2010) Stakeholder Preference Elicitation and Modelling in Multi-Criteria Decision Analysis-A Case Study on Urban Water Supply, European Journal of Operational Research 206:209-220

Macharis, C., Springael, J., De Brucker, K., & Verbeke, A. (2004). PROMETHEE and AHP: The Design of Operational Synergies in Multicriteria Analysis: Strengthening PROMETHEE with Ideas of AHP, European Journal of Operational Research*,* *153*(2), 307-317.

Mankad, A., & Tapsuwan, S. (2011). Review of Socio-Economic Drivers of Community Acceptance and Adoption of Decentralised Water Systems., Journal of Environmental Management, 92(3), 380-391.

Mitchell G, Deletic A, Fletcher T, Hatt B, McCarthy D (2007) Achieving Multiple Benefits from Stormwater Harvesting, Water Science and Technology 55:135-144

Mitchell G, André Taylor, Fletcher T, Deletic A (2006) Integrated Design and Life Cycle Costing of Stormwater Reuse Systems. Institute for Sustainable Water Resources,

Mitchell G, Mein R, McMahon T (2002) Utilising Stormwater and Wastewater Resources in Urban Areas, Australian Journal of Water Resources 6:31-43

Mutikanga, H., Sharma, S., & Vairavamoorthy, K. (2011). Multi-criteria Decision Analysis: A Strategic Planning Tool for Water Loss Management,. Water Resources Management, 25(14), 3947-3969. doi: 10.1007/s11269-011-9896-9

Newnan, D.G., Lavelle, J.P., Eschenbach, T.G. (2002) Essentials of Engineering Economic Analysis, 2nd ed. Oxford University Press, New York.

NRMMC, EPHC, & NHMRC. (2009). Australian Guidelines for Water Recycling (Phase 2): Stormwater Harvesting and Reuse, Natural Resource Ministerial Management Council, Environment Protection and Heritage Council and National Health and Medical Research Council, Canberra, (https://www.clearwater.asn.au/resource-library/guidelines-and-strategy/australian-guidelines-for-water-recycling-phase-2-stormwater-harvest-and-reuse.php).

Öztürké M, Tsoukiàs A, Vincke P (2005) Preference Modelling Multiple Criteria Decision Analysis: State of the Art Surveys:27-59

Philp M et al. (2008) Review of Stormwater Harvesting Practices. Urban Water Security Research Alliance, Retrieved from https://publications.csiro.au/rpr/download?pid=procite:6057d2b6-42b7-4d03-9fd7-ddd451b9d269&dsid=DS1

Pomerol J, Barba-Romero S (2000) Multicriterion Decision in Management: Principles and Practice. Kluwer,

Rowley HV, Peters GM, Lundie S, Moore SJ (2012) Aggregating Sustainability Indicators: Beyond the Weighted Sum, Journal of Environmental Management 111:24-33

Saaty TL (2003) Decision-making with the AHP: Why is the Principal Eigenvector Necessary, European Journal of Operational Research 145:85-91 doi:http://dx.doi.org/10.1016/S0377-2217(02)00227-8

Silva, V. B. S., Morais, D. C., & Almeida, A. T. (2010) A Multicriteria Group Decision Model to Support Watershed Committees in Brazil. Water resources management, 24(14), 4075-4091.

Sharma, A.K.; Pezzaniti, D.; Myers, B.; Cook, S.; Tjandraatmadja, G.; Chacko, P.; Chavoshi, S.; Kemp, D.; Leonard, R.; Koth, B.; Walton, A. (2016) Water Sensitive Urban Design: An Investigation of Current Systems, Implementation Drivers, Community Perceptions and Potential to Supplement Urban Water Services. *Water* 2016, *8(7)*, 272. doi:10.3390/w8070272

Sharma A, Tjandraatmadja G, Cook S, Gardner T (2013) Decentralised Systems–Definition and Drivers in the Current Context, Water Science & Technology 67:2091-2101

Sharma A, Cook S, Tjandraatmadja G, Gregory A (2012a) Impediments and Constraints in the Uptake of Water Sensitive Urban Design Measures in Greenfield and Infill Developments, Water Science and Technology 65:340-352

Sharma A, Tjandraatmadja G, Grant A, Grant T, Pamminger F (2010) Sustainable Sewerage Servicing Options for Peri-Urban Areas with Failing Septic Systems, Water Science and Technology, 62(3), :570-585.

Sharma A, Grant A, Grant T, Pamminger F, Opray L (2009) Environmental and Economic Assessment of Urban Water Services for a Greenfield Development Environmental Engineering Science 26:921-934

Swamee PK, Sharma AK (2008) Design of Water Supply Pipe Networks. Wiley. com,

Taylor A (2005) Guidelines for Evaluating the Financial, Ecological and Social Aspects of Urban Stormwater Measures to Improve Waterway Health. CRC for Catchment Hydrology, Melbourne, Victoria.

Victorian Standing Committee (1999) Urban Stormwater: Best Practice Environmental Management Guidelines by Victorian Stormwater Committee. Collingwood VIC, Australia: CSIRO

Zeleny, M. (1982). Multiple Criteria Decision Making (Vol. 25): McGraw-Hill New York.

Zhang Y, Grant A, Sharma A, Chen D, Chen L (2009) Assessment of Rainwater Use And Greywater Reuse in High-Rise Buildings in a Brownfield Site, Water Science and Technology, 60(3):575-581

Zardari, N. H., Ahmed, K., Shirazi, S. M., & Yusop, Z. B. (2015). Literature Review in Weighting Methods and their Effects on Multi-Criteria Decision-Making Model Outcomes in Water Resources Management (pp. 7-67). Springer, Cham.